5-11-1953

Metal Dust Production

James H. Foreman

METAL DUST PRODUCTION

by

James H. Foreman

MONTANA SCHOOL OF MINES

Butte, Montana

May 11, 1953

METAL DUST PRODUCTION

by

James H. Foreman

A Thesis Submitted to the Department of Metallurgy in Partial Fulfillment of Requirements for a Bachelor of Science Degree in Metallurgical Engineering

MONTANA SCHOOL OF MINES

Butte, Montana

May 11, 1953

TABLE OF CONTENTS

ABSTRACT

The object of this thesis is to study the production of metal dust by direct application of a mechanical force to a stream of molten metal. A stream of the molten metal is directed at the center of a horizontal, rotating disk. The metal moves from the center of the edge by the action of centrifugal force. As the film of metal leaves the disk it is broken up into a fine satellite spray and coarser projected particles. The particles are produced "pencil"shaped. The metal moves from the center to the edge in thin streamers for feed rates below that necessary to completely cover the disk uniformily. For speeds around 2000 r.p.m. this critical feed was found to be over 400g/sec or choke feeding for the low melting point alloy used(eutectic Pb-Sn, M. P. 180° C).

Below this critical feed, the thickness of the streamers is determined primarily by the physical properties of the metal. The temperature of the disk and the metal are not critical within certain limits. Above the upper limit the metal does not solidify and below the lower limit the metal freezes on the disk. A mean temperature range between the disk and the metal was found to vary 55° C without noticably affecting the particle diameter for the low melting point alloy used.

The surface profile does not appreciably effect the particle size produced.

INTRODUCTION

This investigation deals with the production of metal powder by mechanical means. A molten stream of the metal is dropped on the center of a heated disk which revolves horizontally at a high rate of speed. Centrifugal force causes the molten metal to travel to the edge of the disk where the metal impacts the quiescent air and solidifies. As the metal moves from the center ~~the~~ to the edge it is thinned with the increase in normal velocity.

During the past two years considerable work has been done by ~~Mr~~ Messrs. D.S. Gleason,[1] R.F. Payne[3] and C. A. Schroer[2] on the production of zinc dust by this method. Although indications were given and conclusions drawn from their investigations, control seemed to be the hindering factor.

The object of this investigation is to study the various factors involved in metal dust production by the method used, to determine how the particles form and to correlate theory and experimental results to arrive at certain definite conclusions. A low melting point alloy (eutectic Pb-Sn) was used, together with a resistance type heating element for the disk to obtain relatively close temperature control.

Essentially the apparatus is the same as that built by Mr. Gleason and modified by Mr. Schroer and Mr. Payne. Additional modifications made this year will be discussed later.

THEORY

As the molten metal is dropped on the center of the disk, the centrifugal force tends to move the metal from the center to the edge of the disk as a thin film. The normal velocity of the metal film increases to a maximum at the periphery of the disk. Forces acting on the film are the centrifugal force caused by rotation, and the forces of viscosity, surface tension and friction which tend to keep the metal from moving to the edge. Centrifugal force minus the combined forces of surface tension and friction is the force that gives the metal normal velocity.

$$Fc - Ff = Fv$$

$$Fc = \frac{Mv^2}{r}$$

$$Fv = \tfrac{1}{2}MV2$$

$$\tfrac{1}{2}MV^2 = \frac{Mv^2}{r} - Ff$$

$$V^2 = \frac{2v^2}{r} - \frac{2}{M} \quad Ff$$

Where:
- Fc = Centrifugal Force
- Ff = Retaining Forces
- Fv = Force which actually moves the metal to the edge
- M = Mass of particle
- r = radius of the disk
- v = rotational velocity
- v = Normal velocity of the particle

Since the retaining force Ff is constant, the normal velocity depends on the rotational velocity and the radius of the wheel. For a set rotational velocity the normal velocity of the metal is constant.

To have a uniform film completely covering the disk, a certain feed rate must be maintained. This feed rate is set by the rotational velocity of the disk and the retaining forces which are constant. Above this feed rate for a set rate of speed, the thickness of the film would increase.

The actual diameter of the particles produced is determined by the thickness of the film at the outside edge of the disk. As smaller particle size is desired, the feed must be below that required to uniformly cover the disk. If the disk is not covered uniformly there must be some type of breakup occuring on the disk. At a lower rate of feed this breakup would be correspondingly greater.

W.H. Walton and W.C. Prewett[4] have extensively studied the production of liquid sprays by means of spinning disk type sprayers. [4] They found the particle diameter to be related to the factors involved by the following formula.

11 $$d= \frac{3{,}8 \left(\frac{T}{Dp}\right)^{\frac{1}{2}}}{w}$$

Where d= drop diameter, D= disc diameter, w= angular velocity of the disk, T= surface tension of the liquid and p= density of liquid. In their investigations they found that the spray thus formed contained a considerable proportion of fine satellite drops which formed as a cloud. This cloud could be separated from the projected drops by their shorter distance of projection. It was also believed that uniform spray is formed only when drops are formed and released individually from the disc edge. To have uniform spray produced the rate of flow must be small enough so that individual drops are produced. At higher rates of flow the fluid leaves the disc as a thin sheet which breaks up into the satellite spray and the projected spray.

If uniform particle size is desired the breakup must be uniform over the disk, otherwise a broad size distribution is obtained. However this uniform breakup would be hard to obtain with molten metals which have relatively high surface tensions. It is possible that at lower feed rates the breakup might be more uniform and hence more uniform particles would be produced. Molten metal would probably move from the center to the edge in streamers and consequently leave the disk as thin sections and not as individual drops.

The important difference between metal dust production and that of liquid formation is the actual method of particle formation. Metal particles are produced in part by the disintegrating effect of disruption and solidification in the relatively cool air surrounding the disk, while liquid sprays form as individual drops leaving the disk. If this disintegrating effect is prominent then the metal could leave the disk as a thin sheet and still break up uniformly. The impaction of the molten metal on the relatively cold air surrounding the disk tends to break the film up much in the same way as the production of zinc dust by air atomization. This leads to a need of a close temperature control; for if the liquid metal is too hot, disruption will not take place at the edge of the disk and thin sheets of metal will be formed instead of dust. Also if the combined temperatures is too low solidification will take place on the disk.

As it was stated earlier the normal velocity is directly dependent on the rotational velocity. Also the retaining forces are constant. If the rotational velocity and hence the normal velocity are high enough the thickness is determined by the retaining forces which are constant.

Mr. Gleason determined, by using common formulas, the theoretical maximum velocity which the particles could have.

Disregarding retaining forces this calculated to be 123 ft/sec for zinc dust produced at 2000 rpm.

By substituting into Formula I, disregarding the retaining forces.

$$V^2 = \frac{2\,(wr)^2}{r}$$

$$V^2 = \frac{2(2000\text{rpm} \times 1/60 \times 12.7 \times 2\text{x } 3.14)^2}{12.7}$$

$$V \doteq 1{,}062 \text{ cm/sec}$$

Then by applying a material balance to the production of dust. Example zinc dust.

FEED IN	PRODUCT OUT
10g/sec	t x w x c
or	
1.54cc/sec	

1.54= t x w x 79.8cm

To have a continuous band leave the disk per sec, the thickness would be prohibitively small, for the width would have to be the same as the particle speed per sec. Assuming a particle speed of 25ft/sec which is below the calculated maximum, the width would by 760cm and hence the thickness would be .000025cm.

It can be concluded that below the critical feed, surface tension, viscosity and friction are the thickness determining factors. This critical feed is the feed when the disc is just uniformly covered.

The factors involved in dust production are basically, temperature of the disc, temperature of the metal, rotational speed and the rate of feed. During the past two years the shape of the disk was also thought to be an important factor. Walton and Prewett[4] found that "Experiment has shown however that at least in the drop-size range so far investigated the surface profile is a variable of minor importance."

If the feed is below the critical feed the thickness of the film has been shown to be determined by the retaining forces. So any effect of the thinning force caused by surface profiles is overshadowed by the surface tension of the metal which in itself determines the thickness of the film. If the parallel component, which would cause movement along the incline, is less than the maximum, the film would become thicker only to be balanced by the thinning force. (See appendix for calculation) Then actually the surface profile is of minor importance in the production of metal dust.

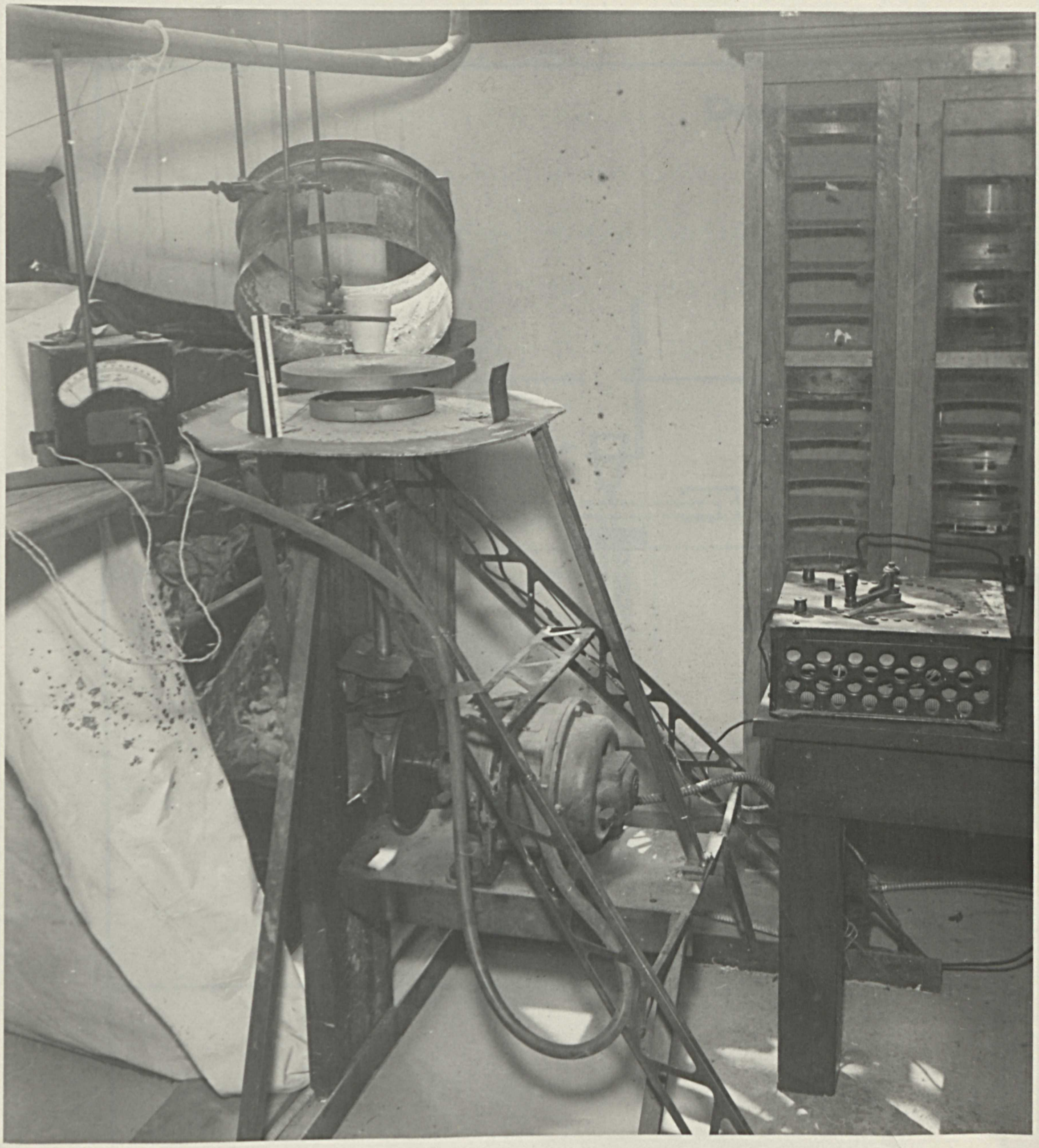
DESCRIPTION OF APPARATUS

The apparatus used was designed and assembled in the Metallurgy Department of the Montana School of Mines. The machine consists of a 10in. horizontal steel disc drive by a 1800 r.p.m., 3 phase, "squirrel cage" motor with a right angle plate and wheel drive. The apparatus is mounted on a channel iron framework which is secured to the concrete floor by stud bolts. The weight of the moving disk and the 1 in. diameter shaft is supported by two thrust bearings bolted to the vertical channel support. The upper bearing is shielded by a sheet metal base, approximately 20 in. in diameter, and another grease shield is placed between the plate and wheel drive unit.

The disk was cut from 3/4 in. boiler plate and the edge machined to a 10 in. diameter. Also the face was lightly machined to produce a smooth surface. The edge was machined with the shaft connected to the disk to obtain a true balance.

This disk was heated by a hot plate unit which was rewired with a heavy electric furnace resistance coil. The plate was mounted on the upper sheet shield just below the disk. Leads to the element came through the shield.

Power supply consisted of the 220 volt A.C. line connected in series



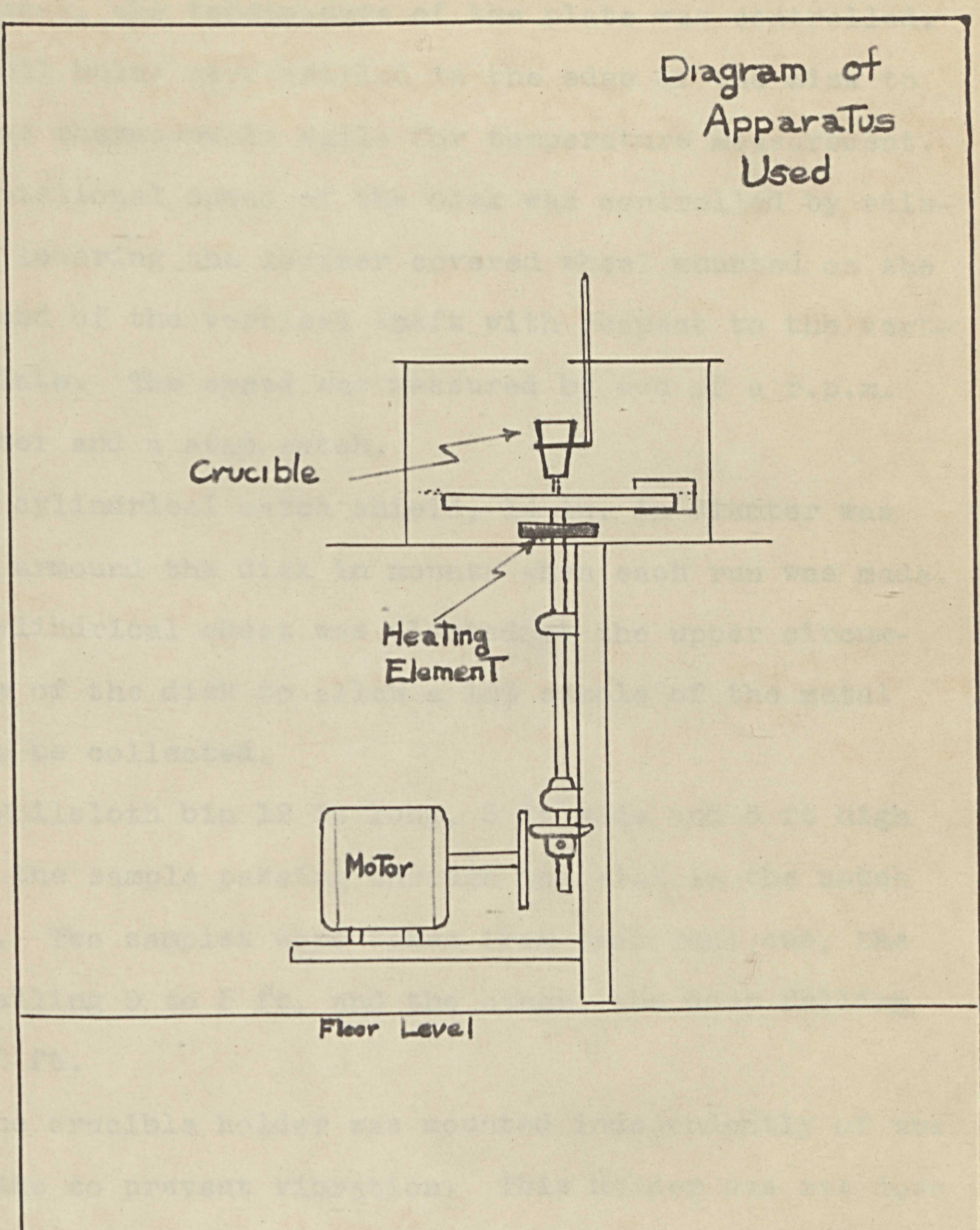


Diagram of Apparatus Used
Crucible
Heating Element
Motor
Floor Level

Fig. 1

with three large variable resistors. By adjusting the resistance, the temperature of the plate was controlled. Two small holes were drilled in the edge of the disk to serve as thermocouple wells for temperature measurement.

Rotational speed of the disk was controlled by raising or lowering the leather covered wheel mounted on the lower end of the vertical shaft with respect to the vertical plate. The speed was measured by use of a r.p.m. indicator and a stop watch.

A cylindrical catch shield, 14 in. in diamter was placed armound the disk in mounts when each run was made. This cylindrical sheet was slotted at the upper circumference of the disk to allow a 10% sample of the metal dust to be collected.

A oilcloth bin 12 ft long, 5 ft wide and 5 ft high caught the sample passing through the slot in the catch shield. Two samples were taken from each run; one, the dust falling 0 to 5 ft, and the other, the dust falling 5 to 12 ft.

The crucible holder was mounted independently of the apparatus to prevent vibration. This holder was set down inside the catch shield so that the distance of metal drop was approximately $\frac{1}{2}$ in.

PROCEDURE

The operating procedure was established for all runs as follows:

1. The metal to be used was melted down in ~~silica~~ fire clay crucibles and held in an electric furnace at the temperature desired. Also the silica pouring crucible was heated at the same time.

2. The rotational speed was set by adjusting the wheel disk coupling.

3. The disk was brought to temperature by the heating element. For the temperatures desired the variable resistances were set at a predetermined point. Heat distribution was uniform throughout. A temperature check was made prior to and following each run. By using the heating oil, the temperature could be held at any predetermined point throughout the run.

4. When both the disk and the metal were at the desired temperature for the run, the motor was turned on and the disk brought up to speed.

5. The feed crucible was removed from the electric furnace and placed in position, then the metal was poured

from the holding crucible and when a sufficient head was reached a cover was removed from the sample slot. The time of run was recorded to determine the feet rate.

6. When the head in the feed crucible dropped, the sample slot was covered and the motor was shut off.

7. The temperature of the disk was then recorded.

8. The samples were collected for hand screening through a 48, 100, and 200 mesh nest.

9. The metal was scraped from the shield and melted down for another test.

EXPERIMENTS

The investigation was divided into different experiments to gather information and data regarding the disintegration of molten metal. By using the low melting point alloy, close control over temperature was possible so the tests were run according to the most convenient order. All test were then divided into their respective experiments. Some tests were applicable to several experiments.

Essentially the following factors effecting dust production were studied.

1. Disk shape

2. Disk temperature

3. Metal temperature

4. Rotational Speed

5. Distance of projection and distribution of dust

6. Feed rate

7. Actual particle formation and metal breakup on the disk.

The tabulated data and also a table of temperature relationships, particle size, feed rates and other data relationships are listed in the appendix. Each experiment performed in this investigation is described and interpreted in the next section.

INTERPRETATION OF DATA

The experiments together with their graphs and interpretations are listed seprately.

1. Disk Shape

The disk shape was studied experimentally by comparing the particle size produced by a flat disk to the particle size produced by a sloped disk, holding all other factors the same. (Tests E and S) A sloped disk was used which had a 60° slope to the horizontal. The feed rate was 10g/sec in both cases, the disk temperature 210° C and the rotational speed was held at 2400 r.p.m.

Although there was a drop in temperature of 50° C in the sloped disk during the run, this did not produce freezing on the disk. Considerable vibration occured during the run.

The graph(Plate I) shows no marked deviation in particle size with surface profile. This comparison is somewhat contrary to the belief, that with a increase in slope there is a more uniform product produced. Although it seems logical that there would be a more uniform break up on the disk with increase in slope.

2. Disk Temperature

The disk temperature was varied holding the metal temperature and other factors constant. Four tests were run using lead held at 370° C as the metal. (Tests A,B,C and D) At a disk temperature of 200° C the lead froze on the disk and at 500° C the lead was too hot to solidify and break up upon leaving the disk.

Plate II shows the relationship of disk temperature to particle size. There seems to be no noticeable change in particle diameter if the disk temperature is neither too hot or too cold. For lead there is a disk temperature range of 100° C where the product is similar.

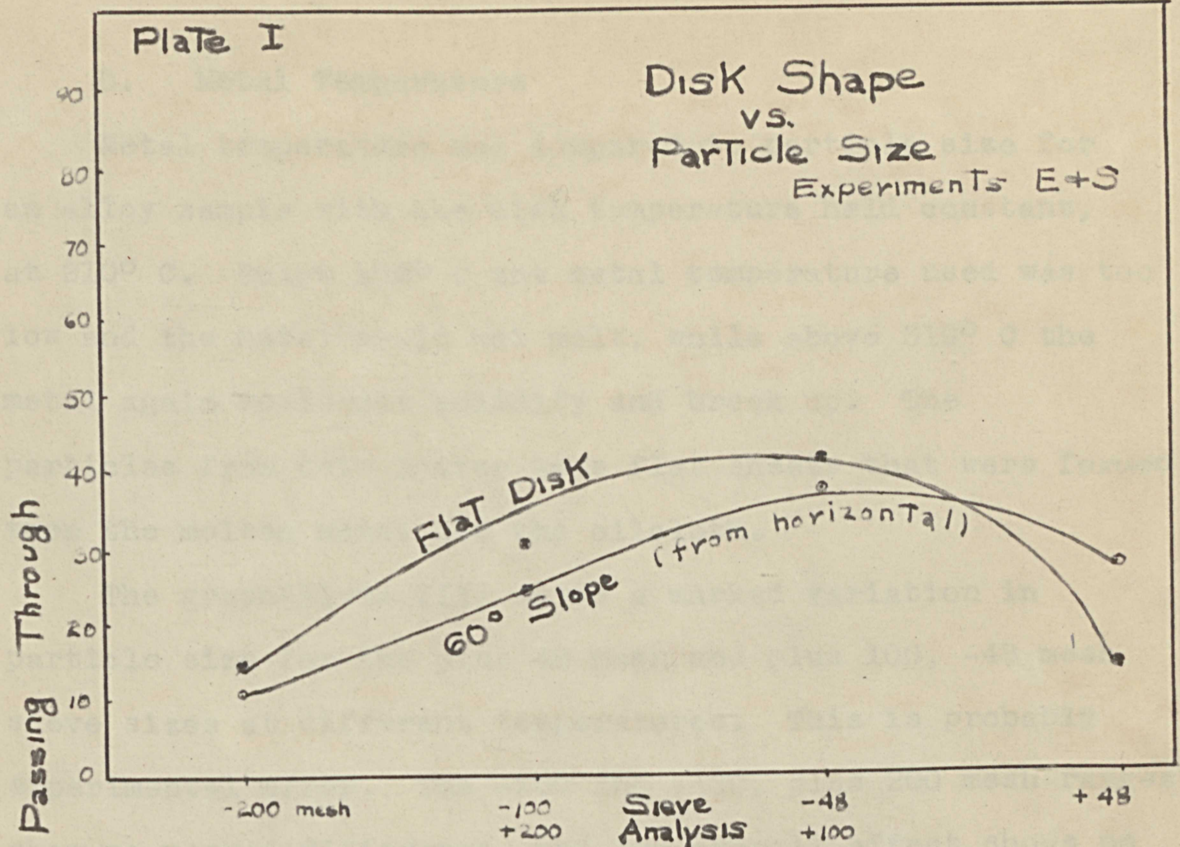


Plate I
Disk Shape
vs.
Particle Size
Experiments E+S
Per Cent Dust Passing Through
Flat Disk
60° Slope (from horizontal)
-200 mesh
-100 +200
-48 +100
+48
Sieve Analysis

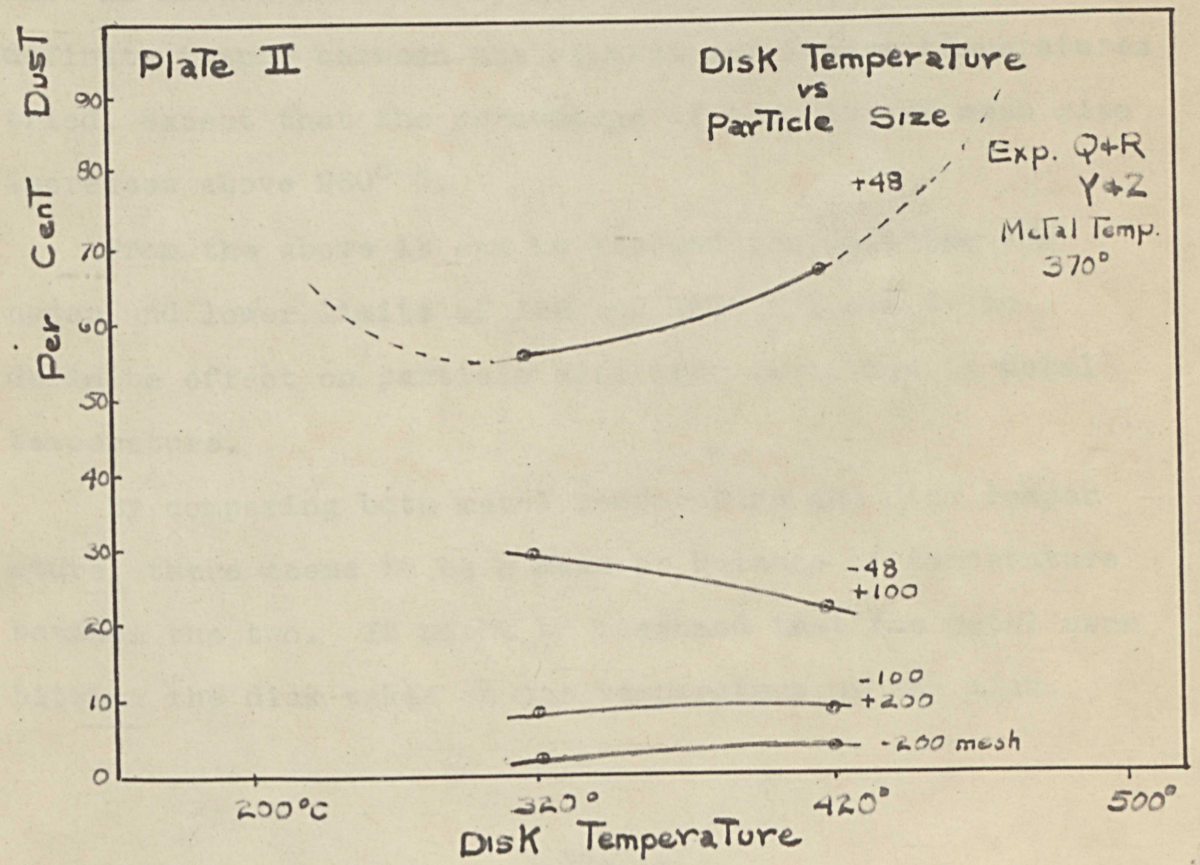


Plate II
Disk Temperature
vs
Particle Size
Exp. Q+R
Y+Z
Metal Temp.
370°
+48
-48 +100
-100 +200
-200 mesh
200°C
320°
420°
500°
Disk Temperature

3. Metal Temperature

Metal temperature was compared to particle size for an alloy sample with the disk temperature held constant, at 210° C. Below 182° C the metal temperature used was too low and the metal would not melt, while above 310° C the metal again would not solidify and break up. The particles from this latter were flat sheets that were formed then the molten metal hit the oilcloth.

The graph(Plate III) shows a marked variation in particle size for the plus 48 mesh and plus 100, -48 mesh sieve sizes at different temperatures. This is probably experimental error. The -200 and -100, plus 200 mesh ranges show no marked difference, and the overall effect shows no definite trends between the highest and lowest temperatures tried, except that the percentage of the plus 48 mesh size increases above 260° C.

From the above it can be assumed that within the upper and lower limits of 182 and 288° C there is no definite effect on particle size with variation in metal temperature.

By comparing both metal temperature and disk temperature, there seems to be a mean or balance of temperature between the two. It might be reasoned that the metal upon hitting the disk takes on the temperature of the disk.

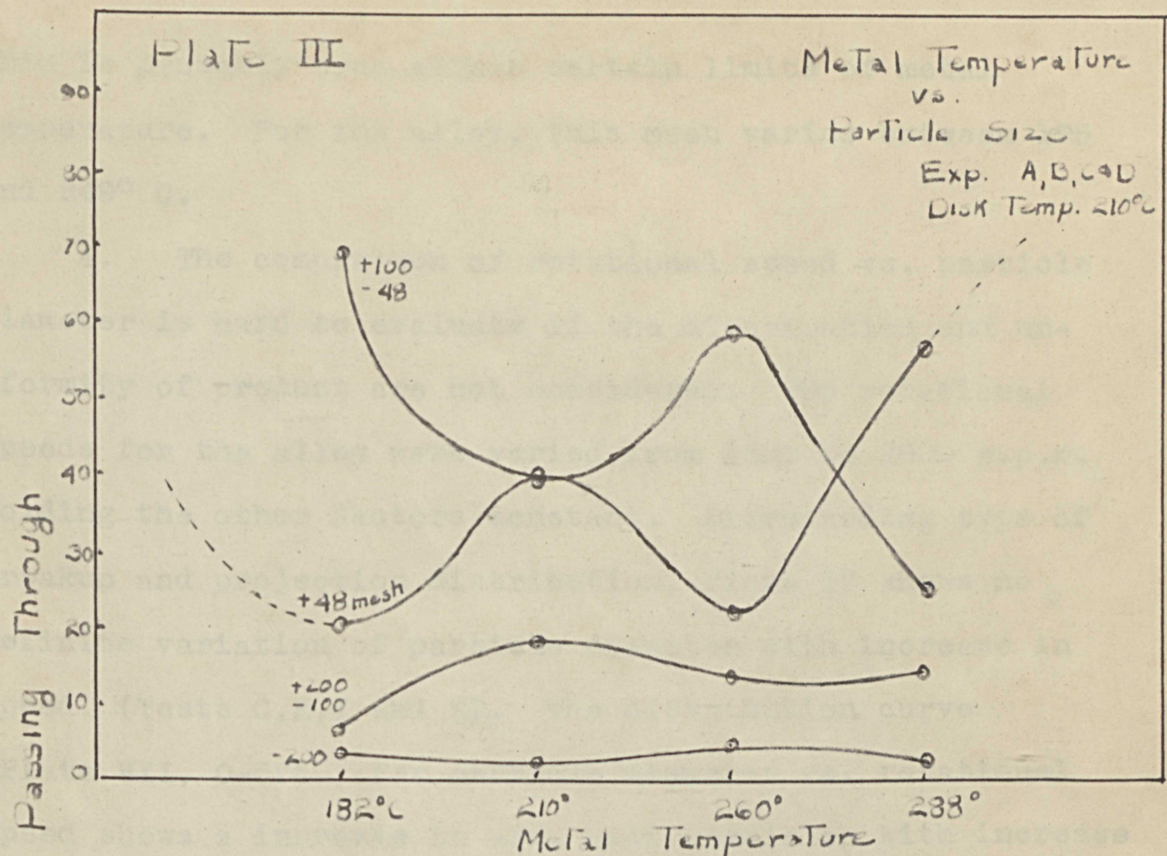


Plate III
Metal Temperature vs. Particle Size
Exp. A, B, C & D
Disk Temp. 210°C
+100 -48
+48 mesh
+200 -100
-200
0 10 20 30 40 50 60 70 80 90
182°C 210° 260° 288°
Metal Temperature
Per Cent Dust Passing Through

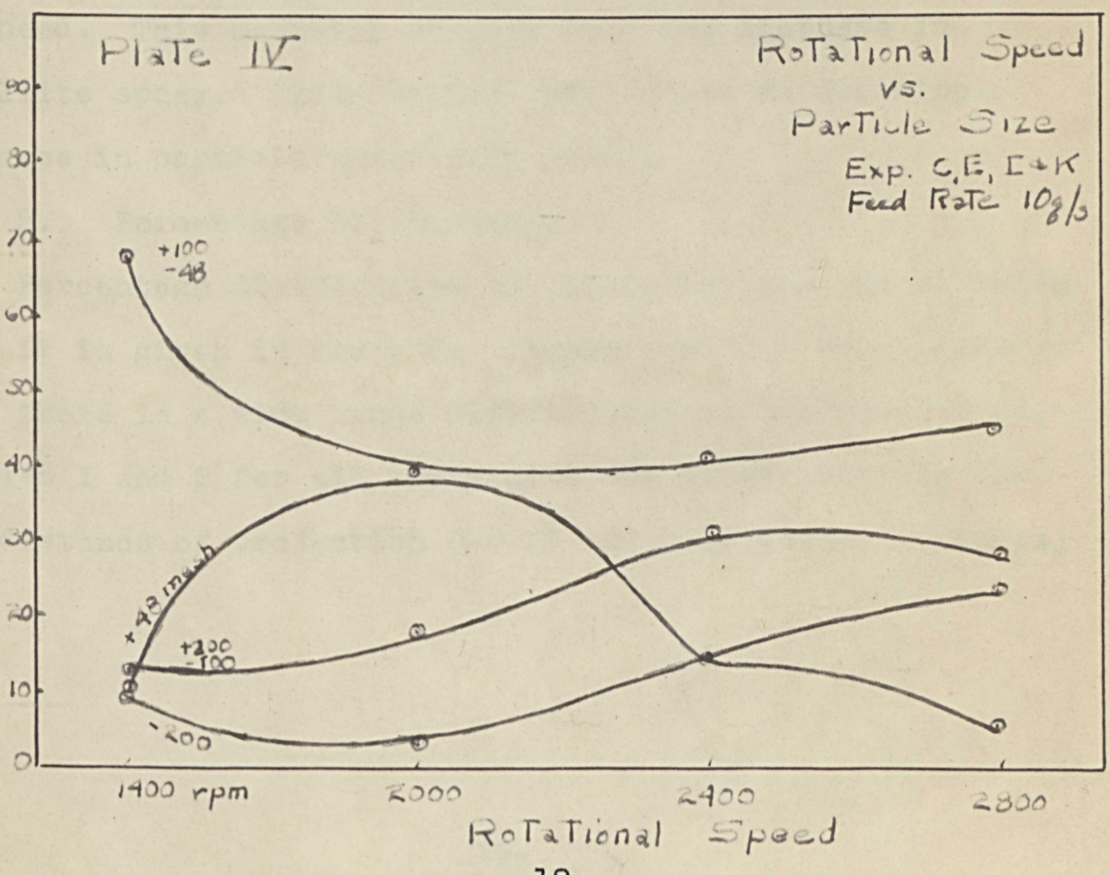


Plate IV
Rotational Speed vs. Particle Size
Exp. C, E, I & K
Feed Rate 10g/s
+100 -48
+48 mesh
+200 -100
-200
0 10 20 30 40 50 60 70 80 90
1400 rpm 2000 2400 2800
Rotational Speed

This is probably true within certain limits of metal temperature. For the alloy, this mean varies between 195 and 249° C.

4. The comparison of rotational speed vs. particle diameter is hard to evaluate if the distribution and uniformity of product are not considered. The rotational speeds for the alloy were varied from 1400 to 2800 r.p.m. holding the other factors constant. Disregarding type of breakup and projection distribution, Plate IV shows no definite variation of particle diameter with increase in speed. (Tests C,E,I and K). The distribution curve (Plate VII, 0-5ft.) for particle diameter vs. rotational speed shows a increase in -200 mesh particles with increase in speed. This probably results from the increase in satellite spray. Plate VIII(5-12ft) shows no definite variance in particle sizes with speed.

5. Percentage Distribution

Percentage distribution of particles over the distance 0-12 ft is given in Plate V. (Experiment H) This shows that there is a wide range distribution of the metal dust. Samples 1 and 2 for all tests give the sieve analysis for the distance of projection 0-5 ft and 5-12 ft(See appendix)

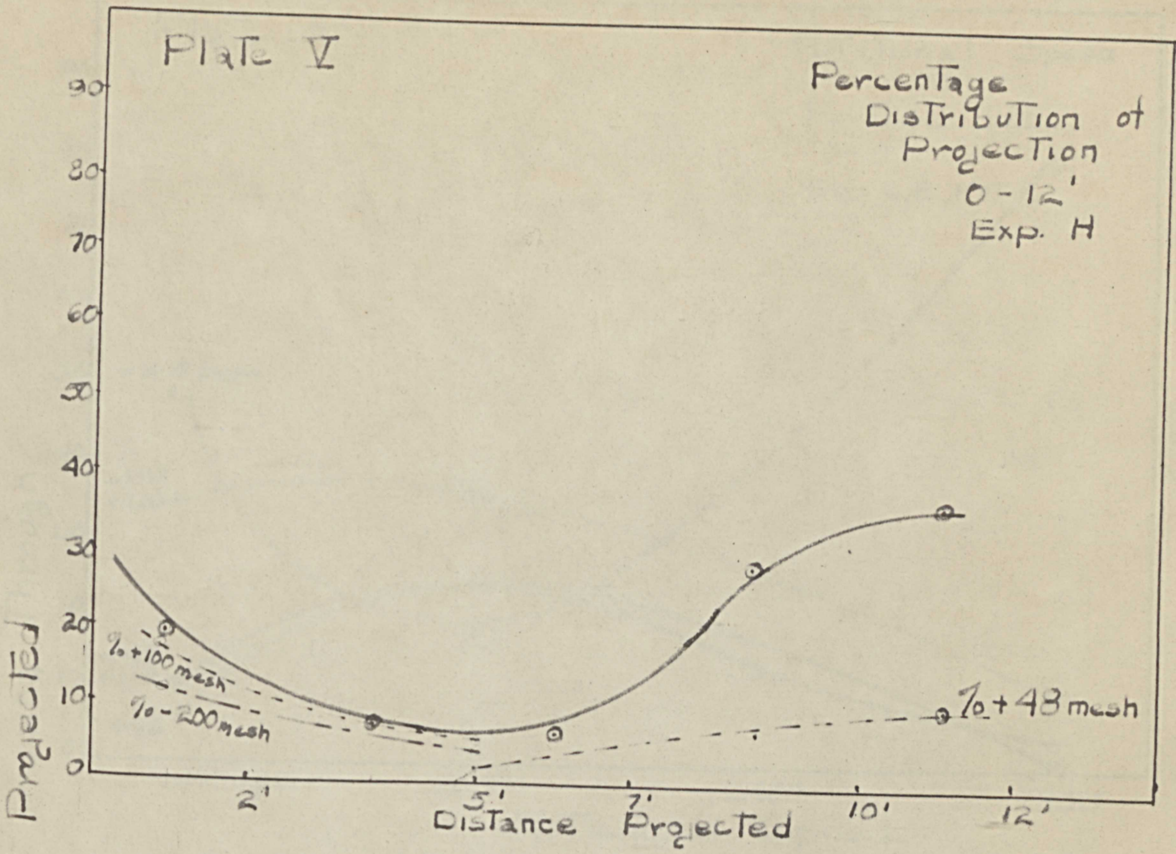


Plate V
Percentage Distribution of Projection 0 - 12'
Exp. H
% +100 mesh
% -200 mesh
% +48 mesh
Distance Projected
Per Cent Dust Projected

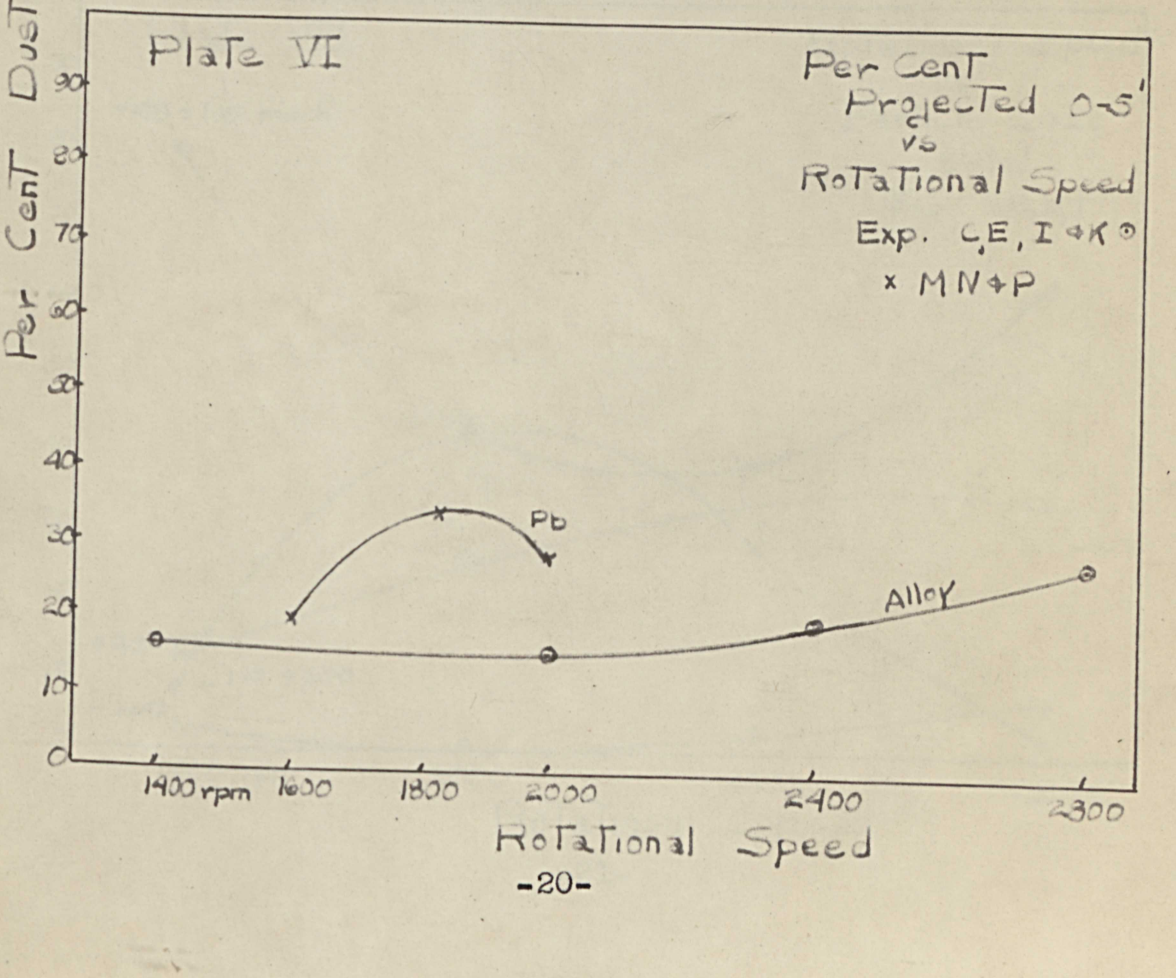


Plate VI
Per Cent Projected 0-5' vs Rotational Speed
Exp. C, E, I & K ⊙
× M N & P
Pb
Alloy
Rotational Speed

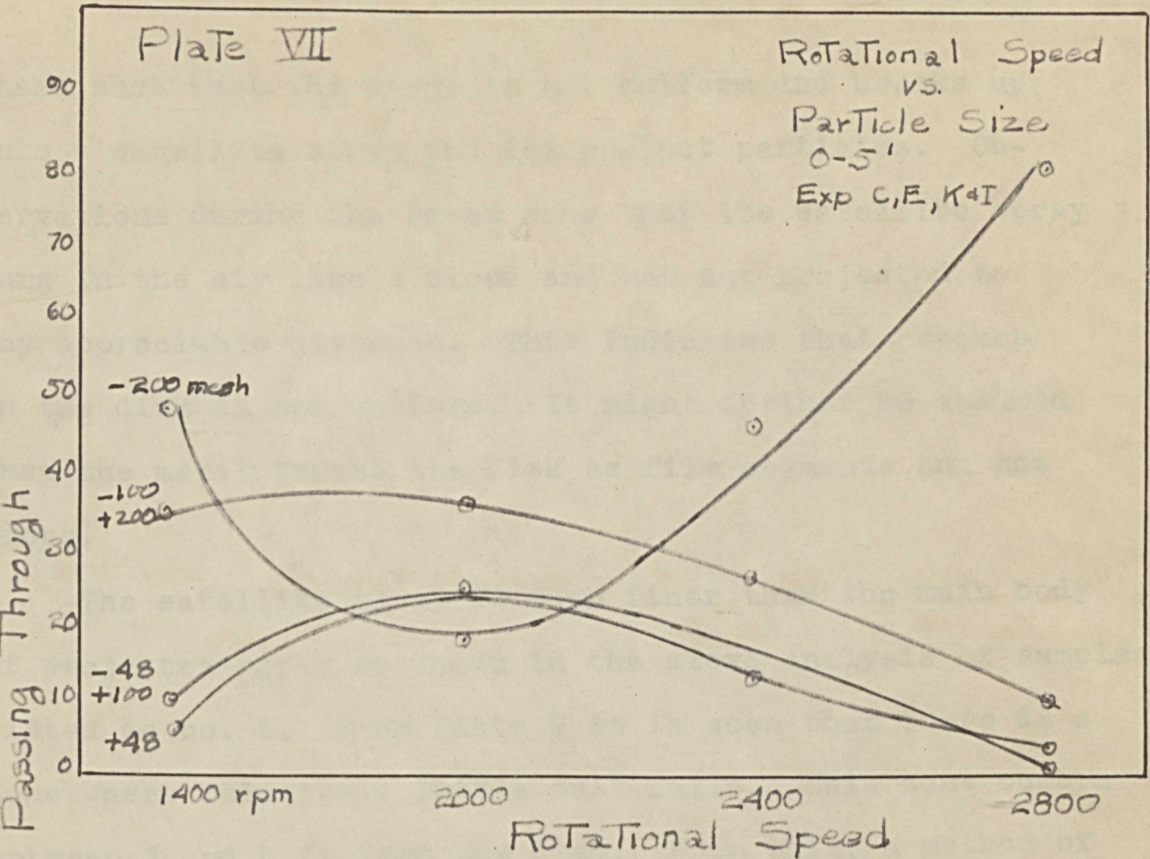


Plate VII
Rotational Speed
vs.
Particle Size
0-5'
Exp C, E, K & I
-200 mesh
-100 +200
-48 +100
+48
90
80
70
60
50
40
30
20
10
0
1400 rpm
2000
2400
2800
Rotational Speed
Per Cent Dust Passing Through

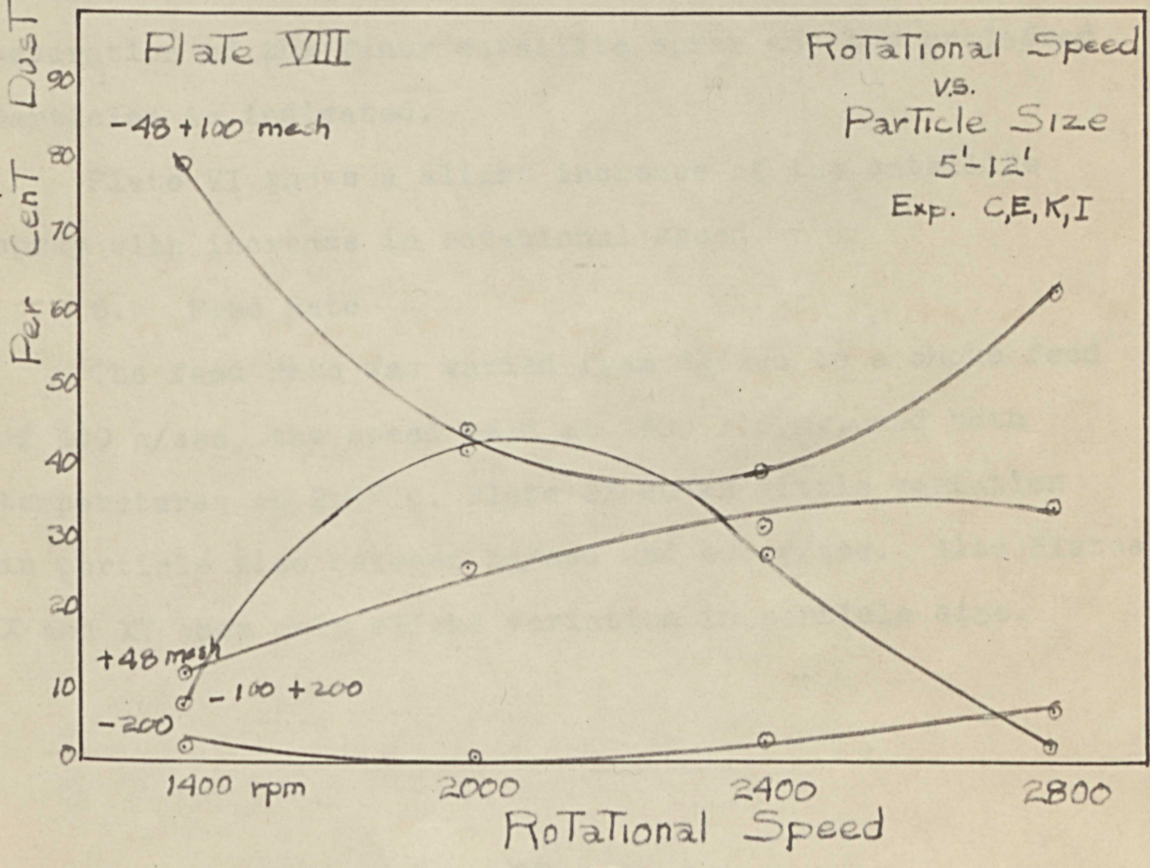


Plate VIII
Rotational Speed
vs.
Particle Size
5'-12'
Exp. C, E, K, I
-48 +100 mesh
+48 mesh
-100 +200
-200
90
80
70
60
50
40
30
20
10
0
1400 rpm
2000
2400
2800
Rotational Speed

These show that the spray is not uniform and breaks up into a satellite spray and the project particles. Observations during the tests show that the satellite spray hung in the air like a cloud and was not projected to any appreciable distance. This indicates that breakup on the disk is not uniform. It might further be assumed that the metal leaves the disk as film segments and not drops.

The satellite spray is much finer than the main body of projected spray as shown in the sieve analysis of samples listed as no. 1. From Plate V it is seen that there is a zone where relatively little dust falls. This zone occurs between 3 and 7 ft from the disk. From this, a method of separation of the finer satellite spray and the projected particles is indicated.

Plate VI shows a slight increase of the satellite spray with increase in rotational speed.

6. Feed Rate

The feed rate was varied from 5g/sec to a choke feed of 400 g/sec, the speed held at 2400 r.p.m., and both temperatures at 210° C. Plate IX shows little variation in particle size between 5g/sec and 400 g/sec. Also Plates X and XI show only slight variation in particle size.

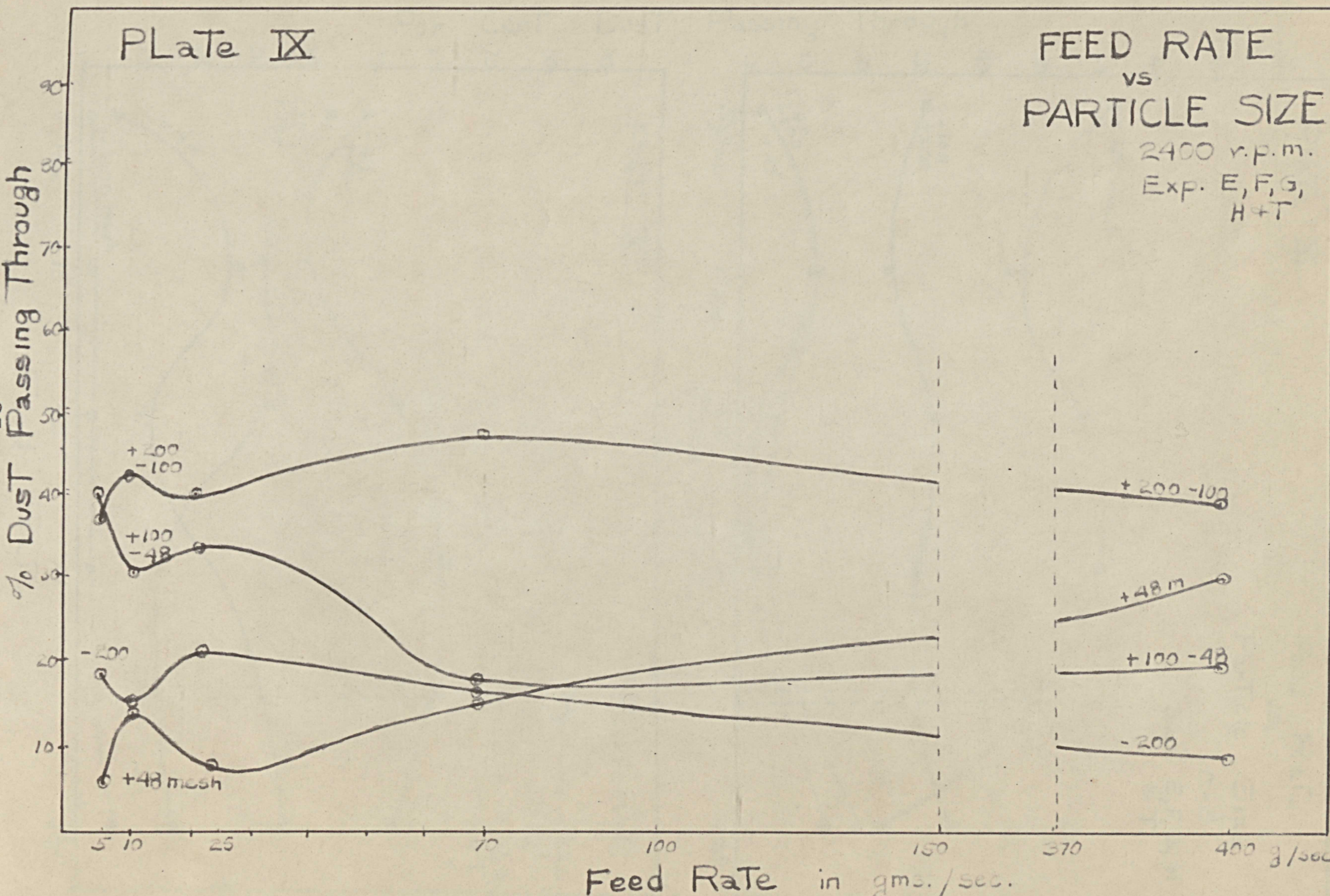


PLaTe IX
FEED RATE
vs
PARTICLE SIZE
2400 r.p.m.
Exp. E, F, G,
H+T
% DusT Passing Through
90
80
70
60
50
40
30
20
10
+200
-100
+100
-48
-200
+48 mesh
+200 -100
+48 m
+100 -48
-200
5
10
25
70
100
150
370
400
g/sec
Feed RaTe in gms./sec.

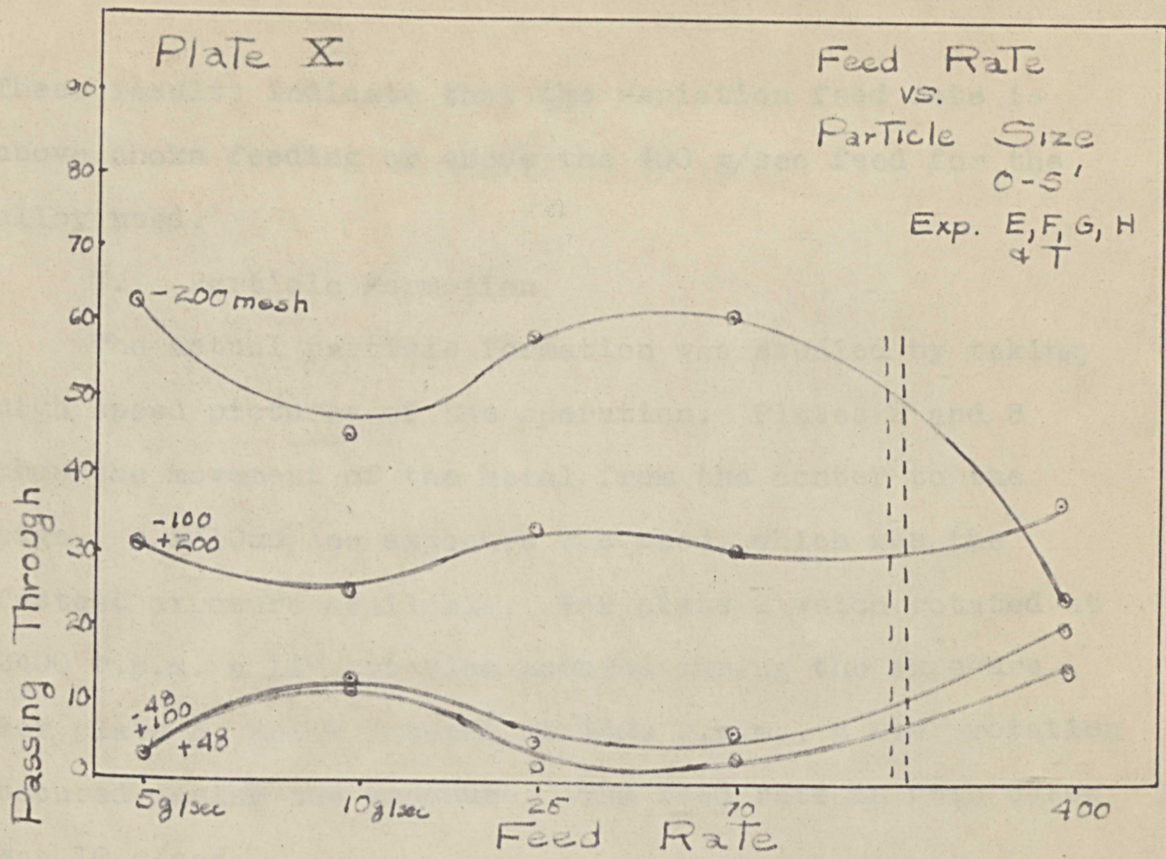


Plate X
Feed Rate vs. Particle Size
0-5'
Exp. E, F, G, H & T
-200 mesh
-100 +200
-48 +100
+48
Per Cent Dust Passing Through
5g/sec
10g/sec
25
70
400
Feed Rate

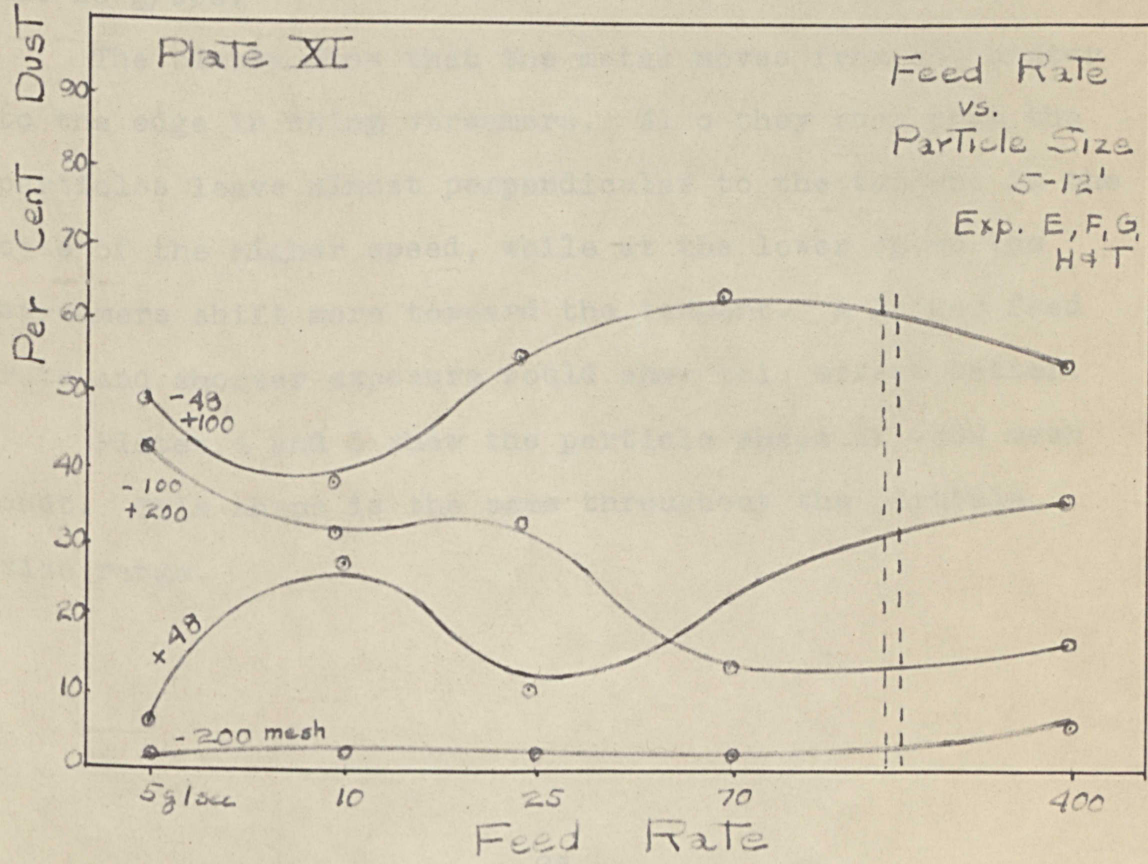


Plate XI
Feed Rate vs. Particle Size
5-12'
Exp. E, F, G, H & T
-48 +100
-100 +200
+48
-200 mesh
5g/sec
10
25
70
400
Feed Rate

These results indicate that the variation feed rate is above choke feeding or above the 400 g/sec feed for the alloy used.

7. Particle Formation

The actual particle formation was studied by taking high speed pictures of the operation. Plates 2 and 3 show the movement of the metal from the center to the edge. A 1/1000 sec exposure was used, which was the fastest exposure available. For plate 2 which rotated at 2400 r.p.m. a 14° rotation occured during the exposure. For plate 3, which rotated at 1400 r.p.m., a 8.4° rotation occured during the exposure. The feed rate in both cases was 10 g/sec.

The plates show that the metal moves from the center to the edge in thin streamers. Also they show that the particles leave almost perpendicular to the tangent in the case of the higher speed, while at the lower speed the streamers shift more toweard the tangent. A larger feed rate and shorter exposure would show this effect better.

Plates 4 and 5 show the particle shape of -300 mesh dust. This shape is the same throughout the particle size range.

PLATE 2

PRODUCTION OF METAL DUST

2400 r.p.m. 1/1000 sec. exp.

PLATE 3

PRODUCTION OF METAL DUST

1400 r.p.m.
1/1000 sec. exposure

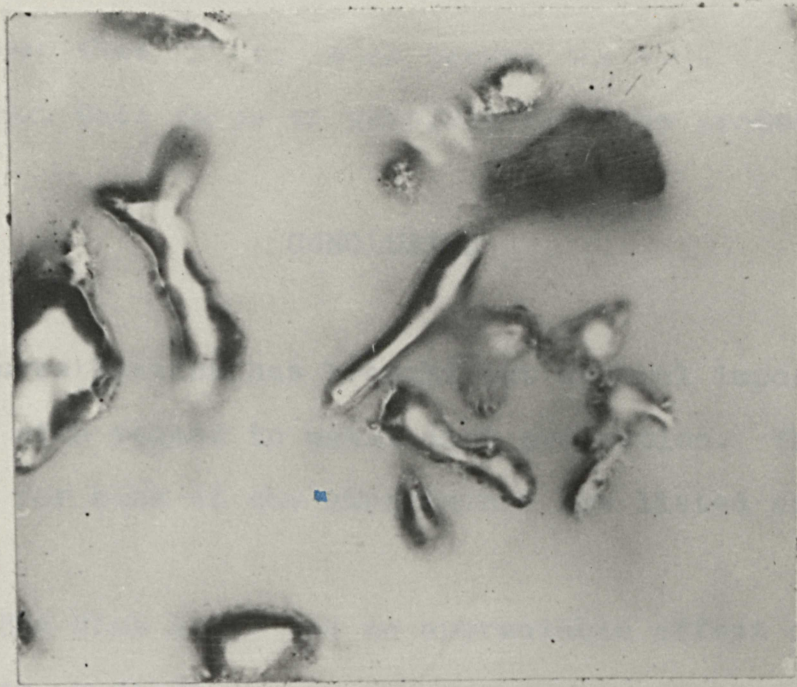


Fig. 4 Alloy Dust -300 mesh, 250X

Fig. 5 Alloy Dust X-Sect. -300 mesh
250 X

It can be seen that if the metal leaves the disk in streamers that this shape of particle would be produced.

CONCLUSION

This investigation has brought out several important indications with regard to metal dust production. The conclusions for each of the experiments are listed as follows.

1. The disk shape has no appreciable effect on the particle size produced.

2. The disk temperature is not critical if held between the upper and lower limits where solidification on the disk occurs, and where no solidification occurs until sometime after the particles leave the disk.

3. The metal temperature follows the same basis, for over a range between the upper and lower limits there is no appreciable variations in particle size.

A balance between the metal temperature and the disk temperature should be calculated for the metal to be used. In this investigation there was a mean temperature between the two for a range of 55° C where the temperature did not effect the partical size to any extent.

4,5 and 6. Rotational speed, type of distribution and the feed rate are all inter-related. For a set rotational speed there is a critical feed rate which is dependent upon the physical properties of the metal. Above this critical feed the thickness of the film would increase and hence the particle diameter would increase. Consequently if the feed is held constant, there is a critical speed, below which the thickness of film and corresponding thickness of particle size would increase with decrease in speed. The critical feed rate was not determined for the alloy when the disk was rotating at 2400 r.p.m., although choke feeding was used. It is evident by particles produced that the critical feed was not reached.

A broad range distribution was found in all cases, that is a satellite cloud and project particles were produced. This indicated that the metal leaves the disk as a thin sheet and not as separate particles.

Below the critical feed for a set r.p.m., the particle diameter depends primarily on the surface tension, viscosity and surface friction of the metal. Therefore below this feed the particle diameter of the product is constant. Above this feed the particle diameter probably would vary directly as the feed rate.

Above the critical r.p.m. for a set feed, the particle size is again dependent on the physical properties of the metal and doesn't vary to any great extent with speed.

It is hard to say what the distribution would be above the critical feed,but from the observations of this investigation, the distribution would be similar to that found in these experiments.

7. The particle shape formed by metal dust production of the alloy is cylindrical "Pencil shaped". (See Plates 4 and 5). This shape is formed by the streamers of metal that move from the center to the edge of the disk. The surface tension is great enough to cause the particles to draw out before breaking away from the surface.

This investigation shows that for the alloy used at a constant r.p,m., the feed rate up to choke feeding doesn't effect the particle size produced; that a satellite spray if formed which is finer that the main projected particles;and that the metal dust is produced by a break up of the thin streamers which serve as a means to move the metal from the center to the edge, resulting in long narrow particles. The potentials of this method can readily be seen. A feed of 400 g/sec would be equivalent to a production of 36 tons per day of alloy dust which would have the following size distribution:

17%	- .074 mm.	or - 200 mesh	
18.4%	- .147mm.	or - 100 mesh	200 mesh
47.5%	- .295 mm.	or - 48 mesh	100 mesh
16.8%	.295 mm.	or 48 mesh	

The particles have a larger surface area per volume then is indicated by the above analysis. Also by separating the satellite spray a much finer dust could be produced.

The formula advanced by Walton and Prewett[4] for liquid sprays gives a calculated particle size that is in close agreement to the actual particle size produced. See page 41 of the appendix for calculations.

RECOMMENDATIONS

To completely evaluate this method of metal dust production a study of feed rates above the critical feed should be employed for different speeds. This could be done by using a slower rotational speed. An extensive study of actual particle formation at the edge of the disk would prove very beneficial. A camera with a shorter exposure time coupled with a greater feed would show just how the particles are formed and break away from the edge of the disk.

ACKNOWLEDGMENTS

The author of this paper would like to take this space to express his appreciation for the valuable advise extended by Dr. F.A. Hames, Professor Ralph Smith and Dr, Earl Roberts of the Metallurgy Department and Professor McGlashan of the Mineral Dressing Department.

Also to record his indebtedness to James Sinclair for valuable laboratory assistance.

BIBLIOGRAPHY

1. Gleason, D.S. "The Production of Powder Zinc." Thesis, Montana School of Mines, 1951.

2. Schroer, C.A. "The Mechanical Production of Zinc Dust." Thesis, Montana School of Mines, 1952.

3. Payne, R.F. "The Mechanical Production of Zinc Dust." Thesis, Montana School of Mines, 1952.

4. Walton, W. H. and Prewett, W.C. " The Production of Sprays and Mists of Uniform Drop Size by Means of Spinning Disc Type Sprayers." Chemical Defence Experimental Station, Porton, Wilts., The Proceedings of the Physical Society, Section B, Vol. 62, Part 6, 1 June, 1949.

EXPERIMENTAL DATA

TEST	FEED	DISK TEMP.	METAL TEMP.	ROTATIONAL SPEED
A	10g/sec.	210°C	260°C	2000 r.p.m.
B	10	210	288	2000
C	10	210	210	2000
D	10	210	182	2000
X *	10	210	156	2000
E	10	210	210	2400
F	5	210	210	2400
G	25	210	210	2400
H	70	210	210	2400
T	400	210	210	2400
I	10	210	210	2800
J	70	210	210	2800
K	10	210	210	1400

* This test run froze immediately upon contact with the disk.

Lead Samples

M	10g/sec	320°C	426°C	2000 r.p.m.
N	10	320	426	1800
O	10	420	426	1600
P	10	320	426	1600
Q	10	420	370	1600
R	10	320	370	1600
S **	10	210	210	2400

** This test was run using the Pb-Sn Alloy on the beveled disk. (60° slope)

Y This test was run under the same conditions as test E except the disk temperature which was 500°C.

SIEVE ANALYSIS

TEST	% projected 0-5'	-200mesh	-100	-48	48
A	22.4 %	4.8 %	13.6 %	59.2 %	22.4 %
B	30.9	2.7	14.1	25.5	57.3
C	15.7	2.7	18.5	39.2	39.7
D	19.8	3.4	6.8	69.0	20.8
E	20.0	14.3	30.6	41.0	14.1
F	24.8	17.3	39.8	37.6	5.3
G	33.2	21.2	33.3	38.1	7.5
H	27.0	17.3	18.4	47.5	16.8
I	28.6	24.6	28.9	45.0	5.5
J	37.4	15.4	29.4	43.0	12.2
K	16.9	9.7	12.6	67.2	10.5
Lead Samples					
M	27.5 %	1.5%	4.6%	12.9%	81.0%
N	35.7	3.9	13.5	38.9	43.7
O	9.5	1.7	10.5	67.5	20.3
P	19.4	2.2	15.9	39.8	43.7
Q	26.4	3.3	8.2	22.0	66.5
R	21.4	2.4	8.1	29.5	55.4
S	18.3	10.6	24.3	37.6	27.5
T	16.0	16.0	21.2	38.4	30.4

Samples S and T were of the alloy.

Samples X, Y, and Z were not screened because of lack of dust. X and Z froze on the disk, while the sample coming off the disk from test Y was still molten.

SCREEN ANALYSIS

Sample #1 for all tests was taken at a distance of 0-5' from the disk.
Sample #2 for all tests was taken at a distance of 5-12' from the disk.

SAMPLE	SIEVE ANALYSIS			
	-200 mesh	-100	-48	48
A-1	17.8%	28.6%	28.6%	25.0%
-2	1.0	9.3	68.1	21.6
B -1	8.7	26.1	26.1	39.1
-2	0.0	8.7	25.2	67.1
C-1	17.9	35.7	25.0	25.0
-2	0.0	1.1	79.6	19.3
D-1	17.4	30.5	26.0	26.1
-2	0.0	15.4	41.6	43.0
E-1	46.6	26.6	13.4	13.4
-2	1.9	31.7	38.6	27.8
F-1	63.6	30.4	3.0	3.0
-2	2.0	43.0	49.0	6.0
G-1	59.1	34.4	4.9	1.6
-2	2.4	32.5	54.5	10.6
H-1	62.0	30.8	6.9	.3
-2	1.5	13.8	62.7	22.0
I -1	81.3	16.1	2.5	1.1
-2	2.0	34.0	62.0	7.0
J-1	30.9	41.7	23.2	4.2
-2	6.2	21.9	65.0	17.0
K-1	48.4	35.4	9.7	6.5
-2	1.9	7.9	79.1	11.2

SAMPLE	SIEVE ANALYSIS -200 mesh	-100	-48	48
Lead Samples				
M-1	2.7%	5.4%	13.6%	78.3%
-2	1.0	4.4	12.6	82.0
N-1	11.1	13.3	17.8	56.8
-2	0.0	13.6	50.6	35.8
O-1	18.5	22.2	22.2	37.1
-2	0.0	9.2	72.2	18.6
P-1	11.7	23.4	17.1	46.8
-2	0.0	14.1	45.1	40.8
Q-1	8.3	14.6	11.4	66.7
-2	1.5	5.9	26.1	66.5
R-1	11.1	20.0	33.4	35.5
-2	0.0	4.8	34.6	60.6
Alloy Samples				
S-1	40.3%	25.0%	7.6%	27.1%
-2	. 2.4	24.6	40.3	32.7
T-1	25.0	37.5	21.9	15.6
-2	5.4	16.2	43.3	35.1

Sample H	Distance of Projection				
Per Cent	0-2'	2-5'	5-7'	7-10'	10-12'
	19.0%	8%	7%	29%	37%

EXPERIMENTAL DATA

Temperature

The metal temperature could only be controlled within limits of 50°C.

Disk temperatures were measured with a Hoskins temperature indicator and a chromel-alumel thermocouple. This unit was standardized and compensated for the readings obtained.

By using the silica pouring crucible no significant temperature drop occured in pouring.

Metals used

Pb-Sn Alloy	melting temperature	183°C
	density	9.30g/cc
Pb	melting temperature	327°C
	surface tension 452 dynes/cm at the melting point.	
	density	11.34g/cc
	viscosity	.028 poise

Sieve analysis

Hand screening

48 mesh	equals	.295 mm.
100 mesh	"	.147 "
200 mesh	"	.074 "

Feed

Orfice Diameter	Feed Rates
.072 in.	5 g/sec
.101 "	10 g/sec
.134 "	25 g/sec
.25 "	70 g/sec
Choke Feed	400 g/sec

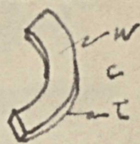
These feed rates were average of the runs timed.

SAMPLE CALCULATION

FEED IN

10 g/sec

PRODUCT OUT



where:

c = circumference of the wheel

w = width of the band

t = thickness of the band

Assume a feed of 10 g/sec which equals 1.54 cc/sec for zinc

$$1.54 \text{ cc/sec} = t \times w \times c$$

$$= t \times w \times 79.8\text{cm}$$

The width of the band, if uniform is equal to the normal velocity of the metal x the time. V x time.

$$V = \frac{1.54 \text{ cc/sec}}{79.8 \text{ cm} \times \text{thickness} \times \text{time}}$$

For the 10g/sec feed rate an average particle diameter proved to be .2mm experimentally or .02cm

$$V = \frac{1.54 \text{ cc/sec}}{79.8 \text{ cm} \times .02\text{cm} \times 1\text{sec}}$$

$$= .965 \text{ cm/sec}$$

This value is far below the calculated maximum value so it can be concluded that breakup does occur on the disk.

Also this equation shows that the thickness is inversely proportional to the normal velocity of the metal. If the disk were sloped the normal velocity would be smaller and hence particle size would be larger.

Comparison of Actual Particle Diameter to the calculated particle diameter from the following formula advanced by Walton and Prewett[4] for liquid sprays.

$$d = \frac{3.8 \left(\frac{T}{DP}\right)^{\frac{1}{2}}}{w}$$

Where: d = drop diameter
D = Disk diameter
w " angular velocity
T " Surface tension of the metal (liquid)
p " density of the liquid)

ZINC DUST produced at 2000 r.p.m.
From experimental results of Mr. Gleason[1] the average particle diameter was between .208 and .417 mm.

$$d = \frac{3.8 \left(\frac{758 \text{ dynes/cm}}{25.4 \times 7.13 \text{g/cc}}\right)^{\frac{1}{2}}}{2000 \text{ rpm} \times 6.28 \times 1/60 \text{ rad/sec}}$$

$= .378$ mm

LEAD DUST produced at 1600 r.p.m. Test O The average particle diameter was .295-.417 mm.

$$d = \frac{3.8 \left(\frac{\cancel{758}\ 452}{25.4 \text{ cm} \times 11.34}\right)^{\frac{1}{2}}}{1600 \times 6.28 \times 1/60}$$

$= .285$ mm

ALLOY DUST produced at 2800 r.p.m.
Note. The true value for the surface tension was not known. Assuming a surface tension of 500 dynes/cm-

$$d = \frac{3.8 \left(\frac{500}{25.4 \times 9.30}\right)^{\frac{1}{2}}}{2800 \times 6.28 \times 1/60}$$

$= .189$ mm

The average particle diameter was between .074 and .417mm
Test I